6.4 GEOTECHNICAL ANALYSIS

An engineering analysis combines the information obtained from the geotechnical field investigation and the laboratory test results to determine the engineering properties and drainage characteristics of the subsurface materials. In addition, the analysis should alert designers, contractors and construction personnel of potential problems and provide economical solutions with consideration given to alternatives. Finally, the analysis should provide an assessment of risk associated with each of the possible solutions. This Section does not give detailed textbook solutions to engineering problems but will provide general guidelines, potential pitfalls of these guidelines and specific references to assist the engineer in performing a detailed analysis.

The quality of the analysis depends on several factors. Knowledge of engineering principles and practical experience in application of these principles is of course very important; but a thorough analysis cannot be accomplished without a clear understanding of the details of the proposed project. This understanding requires a flow of communication and information between project development, bridge design, planning and coordination and the geotechnical engineer. To provide an acceptable analysis of geotechnical information that is practical, economical and of sufficient detail, final alignment and grade are necessary. The project development process must incorporate sufficient time to allow proper investigation and analysis.

At a minimum, the geotechnical analysis should result in a subsurface profile with design soil strength parameters and an engineering evaluation of the subsurface conditions.

The following Sections address the types of projects typical of the Federal Lands Highway Divisions. Within each Section, an outline of typical geotechnical procedures with references to appropriate Exhibits is provided to focus on the more pertinent items. It is beyond the scope of this Chapter to address all details of analysis performed by the Geotechnical Unit. These outlines are only provided to ensure that basic geotechnical items are consistently considered.

6.4.1 Roadway Soils

The vast majority of FLH projects require a roadway investigation. These guidelines presented may be applied to all lengths of roadway projects but the frequency of testing and sampling should be adjusted based upon site specific problems and practical engineering judgment. The following steps provide the basic procedure for typical projects. Sources for site-specific information and detailed references are provided. Typical sample forms are provided that may be used as part of the investigation and analysis process. The following applies:

1. **Initiate Project**. The following applies:
   - Identify available preliminary information (see Form 6.3-A).
   - Obtain or review other pertinent preliminary project development information (e.g., engineering study reports, location study reports, environmental impact documents, design scoping reports)
2. **Review Available Geotechnical Data**. The following applies:

- Review any geotechnical reports and information for projects in the vicinity with emphasis placed on projects on the same route.
- Review published information (see Exhibit 6.3-C). Place emphasis on USDA soil survey information.
- Obtain survey information (e.g., cross sections, drawings, plans).

3. **Plan Field Investigation**. Before performing the field investigation, obtain the following information:
   - Determine drilling requirements (see Exhibit 6.3-E).
   - Review checklists for site investigations (see Form 6.4-H) and roadway cuts and embankments (see Form 6.4-B) to identify needed information to be collected.
   - Determine preliminary equipment requirements (see Exhibits 6.3-B, 6.3-D, 6.3-F and 6.3-K).
   - Determine site restrictions and revise equipment requirements. A site visit may be required.
   - Develop a preliminary boring and testing plan (see Form 6.3-B).

4. **Plan Sampling and Testing**. The following applies:
   - Determine sampling and testing requirements (see Exhibits 6.3-B, 6.3-E and 6.3-G).
   - Record field information (see Exhibits 6.3-H, 6.4-B, 6.4-F and Forms 6.4-C, 6.4-D, 6.4-F, 6.4-H and 6.4-K through 6.4-R, as applicable).

5. **Summarize Field Data**. The following applies:
   - Summarize soil survey information (Form 6.4-D) and water problem areas (Form 6.4-E).
   - Determine appropriate shrink/swell factors (Exhibit 6.4-A).
   - Summarize soil profile information (see Form 6.4-F and Exhibit 6.4-B).

6. **Perform Analysis and Write Report**. Conduct the following:
   - Review the roadway cut and embankment checklist (Form 6.4-B) to ensure all appropriate information is available. Use Exhibit 6.4-C or equivalent to design rock slopes and ditches.
   - Draft a report according to the guidelines presented in Section 6.6.1.

Site Investigation Checklist

Project: ____________________
Location: ____________________
Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box: Yes	No	Not Applicable
1. Is a plan profile (subsurface cross section) of the investigation site provided and clearly identified?			
2. Are the locations of all samples, boring, test pits, probes, geophysical, and field testing shown on a plan view?			
3. Are the locations of the proposed geotechnical features, existing structures, utilities, and other physical site features shown on a plan view?			
4. Are test hole numbers and dates included for each boring or exploration.			
5. Do the profile boring logs contain a word description and/or graphic depiction of soil and rock types?			
6. Is sample type and depth at which each sample was taken noted on the boring logs?			
7. Are SPT blow counts provided on the boring logs?			
8. Are groundwater levels and date measured shown on the boring logs?			
9. Are percent rock core recovery and RQD values shown on the boring logs?			
10. If cone penetrometer probes are made, are logs of cone probes shown, including plots of cone resistance and friction ration with depth?			
11. Is location of other field tests performed at the boring site (such as vane shear, pressure-meter, drive casing, etc.) shown on the boring logs?			
12. Are soil classification tests determined on selected representative samples to verify field visual soil identifications?			
13. Are laboratory test results (natural moisture content, gradation, Atterberg limits, shear strength, consolidation, etc.) included and summarized?			

Form 6.4-A SITE INVESTIGATION CHECKLIST

Roadway Cut and Embankment Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Are station to station descriptions included for:			
a. Existing surface and subsurface drainage?			
b. Evidence of springs and excessively wet areas?			
c. Slides or slumps noted along the alignment?			
2. Are station to station recommendations included for:			
a. Cut slope design?			
b. Are clay slopes designed for minimum FS = 1.50?			
c. Fill slope design?			
d. Will slope design provide minimum FS = 1.25?			
e. Usage of excavated soils?			
f. Estimated shrink-swell factors for excavated materials?			
g. Specific surface/subsurface drainage considerations?			
h. Identifying subexcavation limits of unsuitable soils?			
i. Erosion protection measures for backslopes, sideslopes, and ditches, including riprap or special slope treatments?			
j. Are special blasting specifications needed to insure stable rock slopes and minimize future rockfall?			
k. Need for special rock slope stabilization measures (e.g., rockfall catch ditch, wire mesh slope protection, shotcrete, rock bolts, etc.) identified?			
3. Are recommended contract specifications provided? *Note: Factor of Safety (FS)*			

Form 6.4-B SAMPLE OF ROADWAY CUT AND EMBANKMENT CHECKLIST

Field Mapping – Rock Structures*

1. Location, orientation, and number of planes are numeric. Data units are alphabetic and/or numeric. All other information is alphabetic.
2. Surface type, line type and rock type are three letter codes. Infilling water, form, roughness, and termination are one letter codes.
3. Record all codes and their full proper descriptions on a reference chart.
4. Record position within the data unit or traverse under location. Each data unit should include data from within one structural unit only.
5. Thickness, spacing, and length are entered according to the size notation given below.

Traverse (Data Unit) Information

Data Unit ______ Northing ______ Easting ______ Elevation ______ Inclination ______

Bearing ______ Length ______ No. Points ______ Structural Unit ______ Formation ______ Declination ______ Observer ______

Remarks ____

____

Size Notations (A through I mm, J through S m)

A	<0.26	E	12.5–25	J	0.3–0.6	O	9.0–18.0
B	0.25	F	25–50	K	0.6–1.2	P	18.0–30.0
C	0.25–6.5	G	50–100	L	1.2–2.4	Q	30.0–60.0
D	6.5–12.5	H	100–200	M	2.4–4.5	R	60.0–120.0
		I	200–300	N	4.5–9.0	S	>120.0

Surface type	Infilling	Water	Form	Roughness	Term
C – Contact	A – Clay	W – Wet	P –Planor	V – Very rough(JRC=25)	0 – neither end visble
F – Fault	F – Iron Metals	D – Dry	C –Curved	R – Rough(JRC=15)	1 – one end visble
S – Shear	W – Colcite	M – Moist	U –Undulating	S – Smooth(JRC=5)	2 – both ends visble
J – Joint	K – Chlorite		S –Stepped	P – Polished(JRC=0)	
B – Bedding	Q – Quartz		I –Irregular		
L – Schistosity or Folitation	P – Pyrite				
V – Vein					

Data Unit															Job number			
Location	Surface Type	Orientation Dip	Orientation Direction	Infillings 1	Infillings 2	Infillings 3	Thick	Water	Form	Rough	Spec	No. of Planes	Length	Term	Line Type	Orientation Dip	Orientation Direction	Rock Type

*Detailed instruction in Rock Slopes Design, Excavation, Stabilization by Golder Associates.

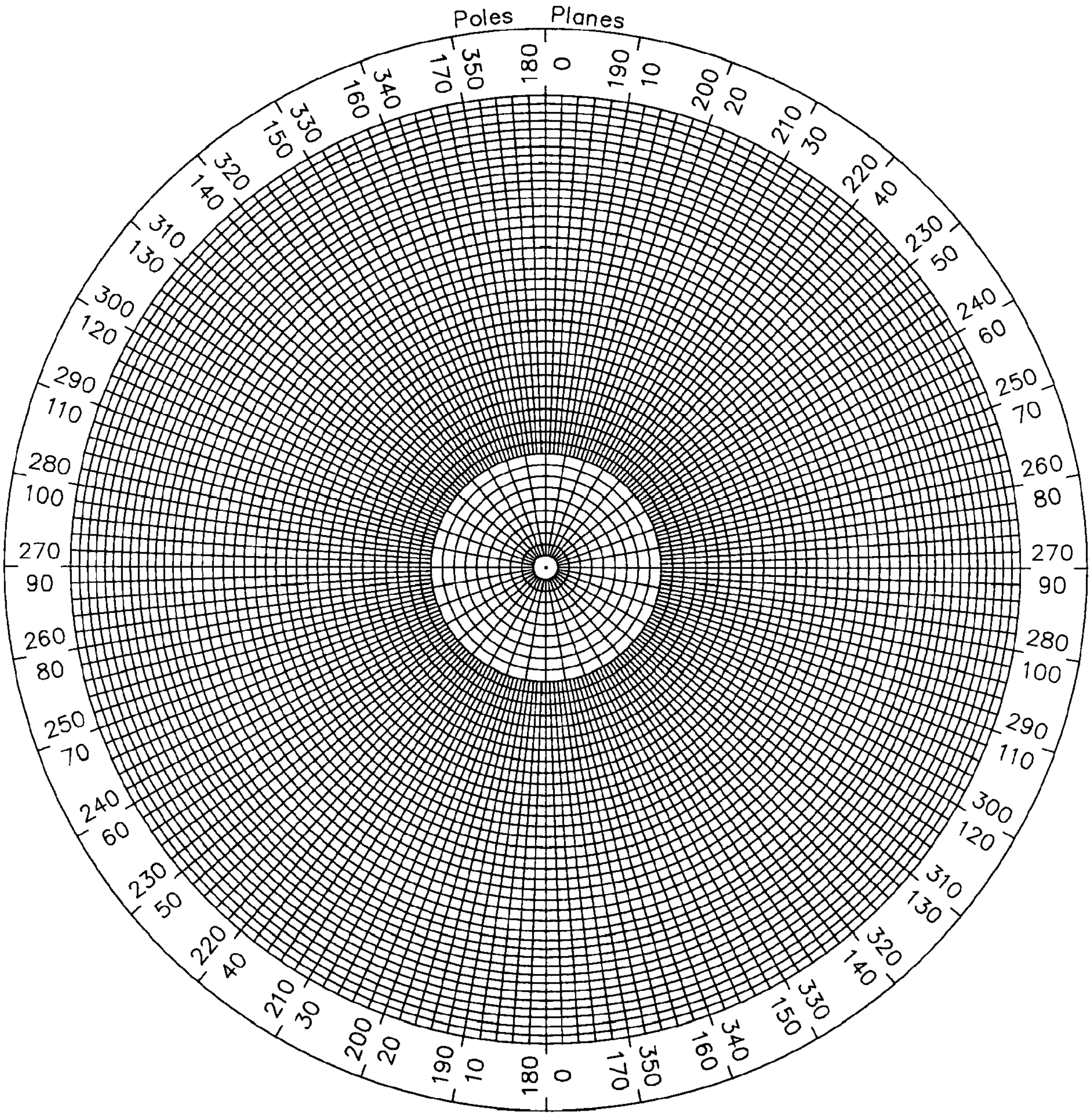
Form 6.4-C FIELD MAPPING – ROCK STRUCTURES*

Field Mapping – Rock Structures* (continued)

Project ____

Location

Plotted by: __________ Date:



Note: plot for data collected from field mapping of the rock structure.

Form 6.4-C FIELD MAPPING – ROCK STRUCTURES*
(Continued)

Summary of Soil Survey

Project: ___________________________________ Date Performed: ______________

Beginning Reference Location: ___________________________ Performed by: _____________

Station to Station	Description of Soil or Rock	Recommended Slope Ratios	Shrink/Swell Factor	Water Problem Area (Yes/No)	Remarks

Form 6.4-D SAMPLE OF SUMMARY OF SOIL SURVEY

Summary of Water Problem Areas

Project: ______________________________

Beginning Reference Location: ______________________________

Performed By: ____________________ Date Performed: ____________________

From Station to Station	Description of Problem	Recommended Solution

Form 6.4-E SUMMARY OF WATER PROBLEM AREAS

Material	Measured				
	In-Situ	Loose		Embankment	
	Mass Density[1] kg/m^3	Mass Density[2] kg/m^3	% Swell[3]	Mass Density[2] kg/m^3	% Swell/Shrink[3]
Andesite	2930	1760	67	2050	43
Basalt	2935	1790	64	2160	36
Bentonite	1600	1185	35	—	—
Breccia	2400	1800	33	1890	27
Calcite-Calcium	2670	1600	67		
Caliche	1440	1245	16	1900	-25
Chalk	2410	1285	50	1810	33
Charcoal	—	610	—	—	—
Cinders	760	570	33	840	-10
Clay					
Dry	1910	1275	50	2120	-10
Damp	1985	1180	67	2205	-10
Conglomerate	2205	1660	33		
Decomposed rock					
75% R. 25% E.	2445	1865	31	2185	12
50% R. 50% E.	2225	1610	38	2375	-6
25% R. 75% E.	2005	1405	43	2205	-9
Diorite	3095	1855	67	2165	43
Diotomaceous earth	870	540	62		
Dolomite	2890	1725	67	2015	43
Earth, loam					
Dry	1795	1230	50	2090	-12
Damp	2000	1400	43	2090	-4
Wet, mud	1745	1745	0	2090	-20
Gabbro	2615	1565	67	1825	43
Feldspar	3095	1855	67	2165	43
Gneiss	2700	1615	67	1885	43
Gravel					
Dry—					
Uniformly Graded	1770	1600	10	1870	-5
Average Gradation	1945	1620	20	2120	-8
Well Graded	2180	1645	33	2450	-11
Wet—					
Uniformly Graded	1965	1870	5	1870	-5
Average Gradation	2160	1950	10	2120	-2
Well Graded	2425	2090	16	2450	-1
Granite	2695	1565	72	1880	43
Gumbo					
Dry	1915	1275	50	2120	-10
Wet	1985	1200	67	2205	-10
Gypsum	2420	1410	72		
Igneous rocks	2795	1675	67	1960	43

Exhibit 6.4-A SHRINK/SWELL FACTORS FOR COMMON MATERIALS*
(Metric)

Material	Measured				
	In-	Loose		Embankment	
	Mass Density[1], kg/m^3	Mass Density[2] kg/m^3	% Swell[3]	Mass Density[2] kg/m^3	% Swell/Shrink[3]
Kaolinite					
Dry	1915	1275	50		
Wet	1985	1190	67		
Limestone	2600	1595	63	1910	36
Loess					
Dry	1910	1275	50	2120	-10
Wet	1985	1190	67	2205	-10
Marble	2680	1600	67	1875	43
Marl	2220	1330	67	1555	43
Masonry, rubble	2325	1395	67	1630	43
Mica	2885	1725	67		
Pavement					
Asphalt	1920	1150	50	1920	0
Brick	2400	1440	67	1685	43
Concrete	2350	1405	67	1645	43
Macadam	1685	1010	67	1685	0
Peat	700	530	33		
Pumice	640	385	67		
Quartz	2585	1550	67	1780	43
Quartzite	2680	1610	67	1875	43
Rhyolite	2400	1435	67	1700	43
Riprap rock	2670	1550	72	1870	43
Sand					
Dry	1710	1535	11	1920	-11
Wet	1835	1915	5	2050	-11
Sandstone	2415	1495	61	1795	34
Schist	2685	1610	67	1880	43
Shale	2640	1470	79	1775	49
Shale	1920	1410	36	2310	-17
Siltstone	2415	1495	61	2705	-11
Slate	2670	1540	77	1870	43
Talc	2750	1650	67	1930	43
Topsoil	1440	960	56	1945	-26
Tuff	2400	1600	50	1810	33

Notes:

1. *Subject to average ±5% variation.*
2. *Mass densities are subject to adjustments in accordance with modified swell and shrinkage factors.*
3. *Based on average in-situ densities. A negative number represents a shrinkage. Factors subject to ±33% variation.*

Exhibit 6.4-A SHRINK/SWELL FACTORS FOR COMMON MATERIALS
(Metric)
(Continued)

Material	Measured				
	In-Situ	Loose		Embankment	
	Mass Density[1] lb/ft^3	Mass Density[2] lb/ft^3	% Swell[3]	Mass Density[2] lb/ft^3	% Swell/Shrink[3]
Andesite			67		43
Basalt			64		36
Bentonite			35		—
Breccia			33		27
Calcite-Calcium			67		
Caliche			16		-25
Chalk			50		33
Charcoal			—		—
Cinders			33		-10
Clay					
Dry			50		-10
Damp			67		-10
Conglomerate			33		
Decomposed rock					
75% R. 25% E.			31		12
50% R. 50% E.			38		-6
25% R. 75% E.	*To Be*		43	*To Be*	-9
Diorite	*Provided*		67	*Provided*	43
Diotomaceous earth			62		
Dolomite			67		43
Earth, loam					
Dry			50		-12
Damp			43		-4
Wet, mud			0		-20
Gabbro			67		43
Feldspar			67		43
Gneiss			67		43
Gravel					
Dry—					
Uniformly Graded			10		-5
Average Gradation			20		-8
Well Graded			33		-11
Wet—					
Uniformly Graded			5		-5
Average Gradation			10		-2
Well Graded			16		-1
Granite			72		43
Gumbo					
Dry			50		-10
Wet			67		-10
Gypsum			72		
Igneous rocks			67		43

Exhibit 6.4-A SHRINK/SWELL FACTORS FOR COMMON MATERIALS
(US Customary)
(Continued)

Material	Measured				
	In-	Loose		Embankment	
	Mass Density[1,] lb/ft^3	Mass Density[2] lb/ft^3	% Swell[3]	Mass Density[2] lb/ft^3	% Swell/Shrink[3]
Kaolinite					
Dry			50		
Wet			67		
Limestone			63		36
Loess					
Dry			50		-10
Wet			67		-10
Marble			67		43
Marl			67		43
Masonry, rubble			67		43
Mica			67		
Pavement					
Asphalt			50		0
Brick			67		43
Concrete			67		43
Macadam			67		0
Peat			33		
Pumice	*To Be Provided*		67	*To Be Provided*	
Quartz			67		43
Quartzite			67		43
Rhyolite			67		43
Riprap rock			72		43
Sand					
Dry			11		-11
Wet			5		-11
Sandstone			61		34
Schist			67		43
Shale			79		49
Shale			36		-17
Siltstone			61		-11
Slate			77		43
Talc			67		43
Topsoil			56		-26
Tuff			50		33

Notes:

1. *Subject to average ±5% variation.*
2. *Mass densities are subject to adjustments in accordance with modified swell and shrinkage factors.*
3. *Based on average in-situ densities. A negative number represents a shrinkage. Factors subject to ±33% variation.*

Exhibit 6.4-A SHRINK/SWELL FACTORS FOR COMMON MATERIALS
(US Customary)
(Continued)

Interpreted Design Soil Profile

Material Number	Description	Soil Parameters		
		C	ϕ	γ_T

Form 6.4-F SAMPLE OF INTERPRETED DESIGN SOIL PROFILE

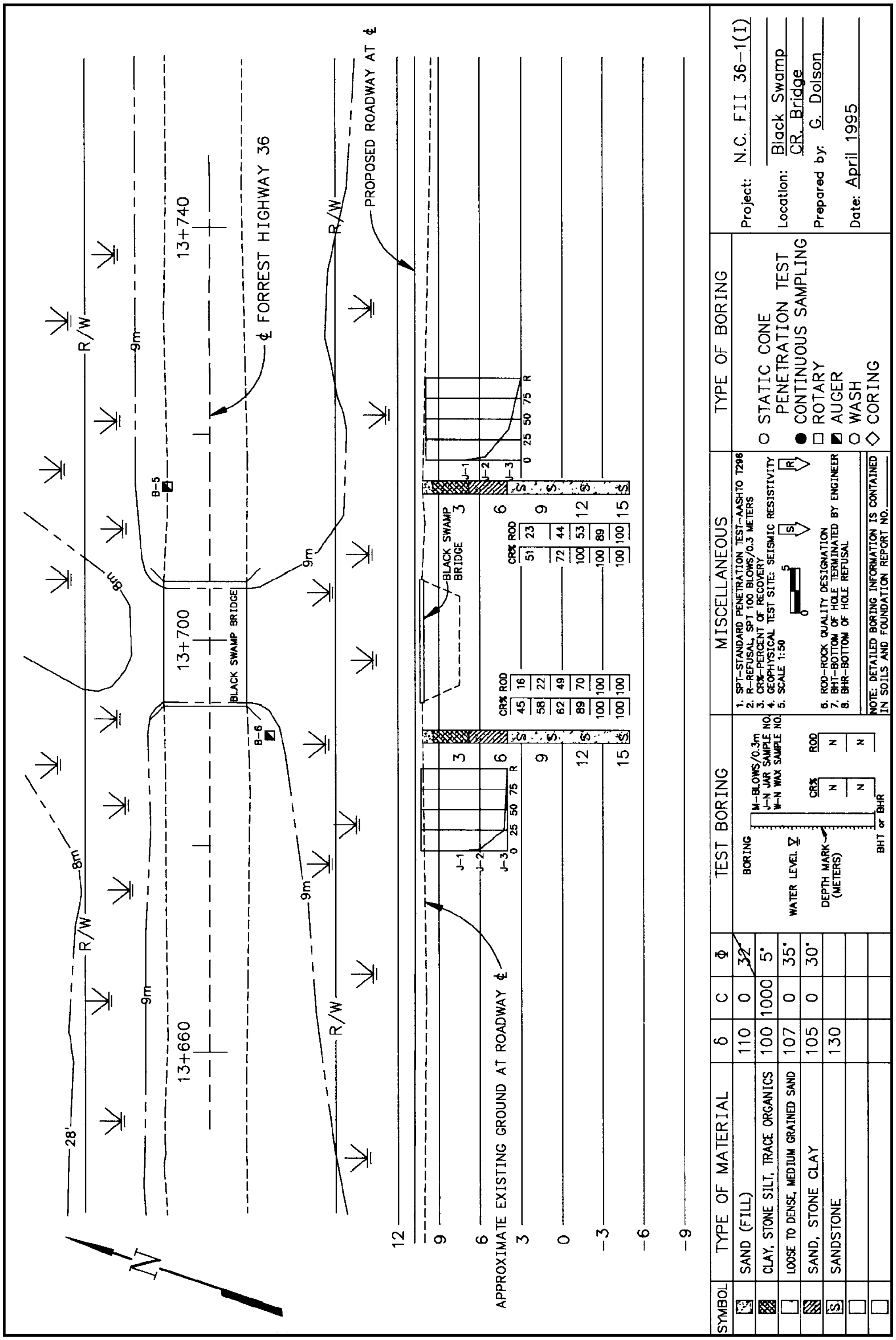


Exhibit 6.4-B SAMPLE OF A SOILS AND FOUNDATION PLAN AND PROFILE SHEET

General Report Checklist

Project: ____________________

Location: ____________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box: Yes	No	Not Applicable
1. Is a title page included?			
2. Is a vicinity map included?			
3. Is a standard report format followed? (i.e., introduction, results, discussion, recommendation, details and appendices)			
4. Is the scope and purpose of report and authority for investigation summarized in the introduction?			
5. Is the summary of field explorations and lab testing given in the results?			
6. Is the description of general subsurface soil, rock and groundwater conditions given in the results?			
7. Are concise descriptions given for geologic features and topography of the area in the discussion?			
8. Are recommendations concise and in sufficient detail to design the project or serve the intended purpose?			
9. Is the following information included with the geotechnical report? (Typically included in report appendices): •Test hole logs? •Laboratory test data? •Field test data? •Photographs?			

Comments ____________________

____

Form 6.4-G SAMPLE OF GENERAL REPORT CHECKLIST

Site Investigation Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box		
	Yes	**No**	**Not Applicable**
1. Is a plan profile (subsurface cross section) of the investigation site provided and clearly identified?			
2. Are the locations of all samples, boring, test pits, probes, geophysical, and field testing shown on a plan view?			
3. Are the locations of the proposed geotechnical features, existing structures, utilities and other physical site features shown on a plan view?			
4. Are test hole numbers and dates included for each boring or exploration.			
5. Do the profile boring logs contain a word description and/or graphic depiction of soil and rock types?			
6. Is sample type and depth at which each sample was taken noted on the boring logs?			
7. Are SPT blow counts provided on the boring logs?			
8. Are groundwater levels and date measured shown on the boring logs?			
9. Are percent rock core recovery and RQD values shown on the boring logs?			
10. If cone penetrometer probes are made, are logs of cone probes shown, including plots of cone resistance and friction ration with depth?			
11. Is location of other field tests performed at the boring site (e.g., vane shear, pressure-meter, drive casing, etc.) shown on the boring logs?			
12. Are soil classification tests determined on selected representative samples to verify field visual soil identifications?			
13. Are laboratory test results (natural moisture content, gradation, Atterberg limits, shear strength, consolidation, etc.) included and summarized?			

Form 6.4-H SAMPLE OF SITE INVESTIGATION CHECKLIST

Rock Slope: Near Vertical		
H	W	D
4.5–9.0	2.4	0.9
9.0–18.0	3.6	1.2
Over 18	5.5	1.2
Rock Slope: 4:1 & 3:1		
H	W	D
4.5–9.0	2.4	0.9
9.0–18.0	3.6	1.2
18.0–30.0	5.5	1.8
Over 30	7.6	1.8
Rock Slope: 2:1		
H	W	D
4.5–9.0	2.4	1.2
9.0–18.0	3.6	1.8
18.0–30.0	5.5	1.8
Over 30	7.6	2.4
Rock Slope: 1.3:1		
H	W	D
0–9.0	2.4	0.9
9.0–18.0	3.6	1.2
Over 18	3.6	1.8
Rock Slope: 1:1		
H	W	D
0.9–9.0	2.4	0.9
9.0–18.0	3.0	1.5
Over 18	3.6	1.8
Rock Slope: 1:1.25		
Use rock fence on shoulder.		

Note: All dimensions in meters.

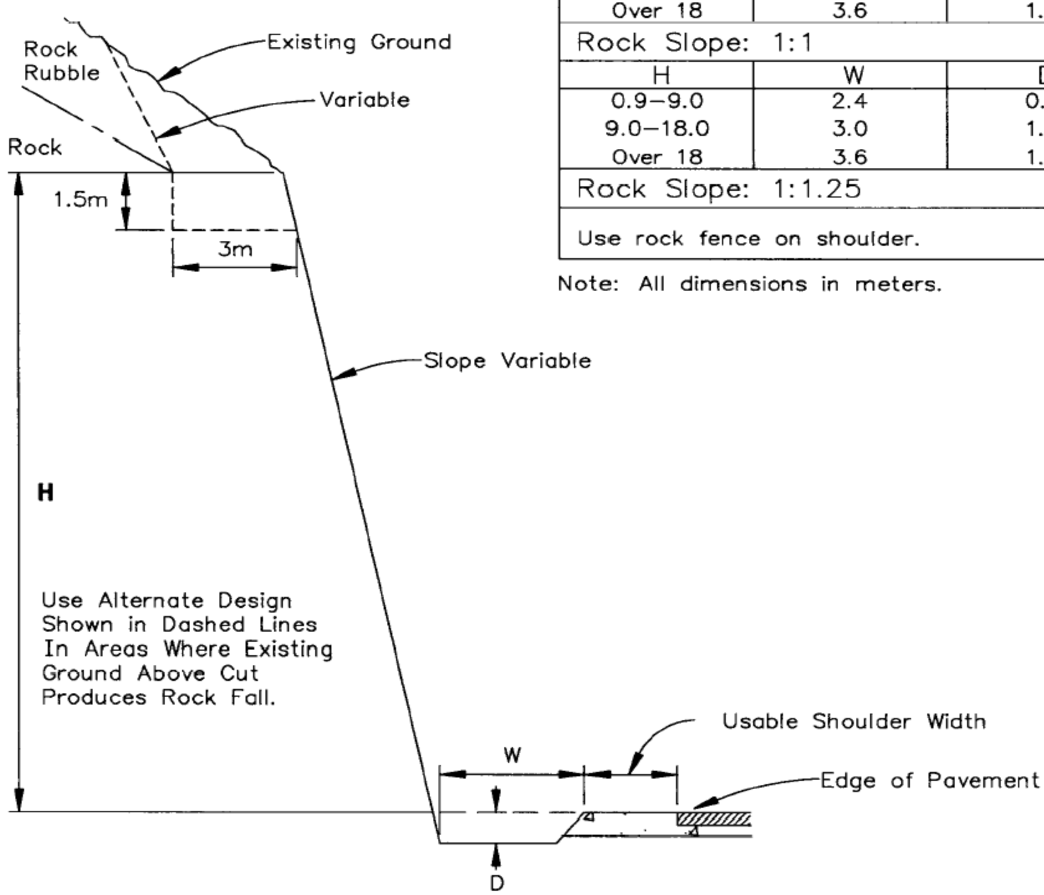


Exhibit 6.4-C ROCK SLOPE DESIGN CRITERIA*
(Metric)

To Be Provided

Exhibit 6.4-C ROCK SLOPE DESIGN CRITERIA*
(US Customary)

- Refer to the general report checklist (Form 6.4-G) and the site investigation checklist (Form 6.4-H) to ensure appropriate report content.

- Finalize the report.

On longer projects, the sampling frequency may be reduced. Therefore, more emphasis needs to be placed on carefully inspecting and assembling the field information and laboratory test results to determine sections of roadway with similar characteristics. The characteristics that are of primary importance are in-situ material properties and existing conditions. Other items (e.g., proposed use, surface and subsurface water, vertical and horizontal alignment (cut/fill)) can also influence the analysis. The selection of the grouping factors used to identify similarities is usually determined by problems that are likely to be encountered on a specific project. Obviously, this type of analysis requires practical experience for effective implementation. Exhibit 6.4-D provides some guidance in selecting detailed factors and conditions that may be used. Exhibit 6.4-A may be used to estimate unit weights and shrink/swell factors.

After determining areas with similar conditions and material, engineering properties are assigned to materials for evaluation and design. These properties are determined either from direct laboratory tests or from correlated and/or assumed properties from manuals or textbooks referenced in Section 6.2. The analysis of a roadway soil investigation should concentrate on defining area limits and the severity of the following problems and conditions:

- establish design cut and fill slope ratios;
- locate suitable materials for embankments;
- identify shrink/swell factors for excavation;
- identify areas requiring subexcavation;
- locate wet areas (e.g., seepage of excessive water);
- identify potential areas of instability; and
- determine the subgrade strength values for pavement structure design.

6.4.2 Structure Foundations

One of the most critical steps in analyzing structural foundations is the selection of foundation types that are applicable to specific site conditions. To systematically select or eliminate types of foundations, the following steps should be considered:

1. **Identify**. Identify the type of superstructure and loads to be applied to the foundation.

2. **Define**. Define and summarize subsurface conditions.

3. **Assess**. Subjectively assess the applicability of each type of foundation for their capability of carrying the required loads and estimate the amount of settlement that is likely.

4. **Eliminate**. Eliminate obviously unsuitable foundation types and prepare detailed studies and/or tentative designs for new foundations.

Identifying Characteristic	Potential Problem/Condition					
	Soil/Rock Interface	Variability of Pavement	Settlement	Frost Heave	Poor Drainage	Slope Instability
In-Situ Properties						
Soil Classification	X	X	X	X	X	X
Plasticity			X	X	X	X
Natural Moisture	X		X		X	X
Subgrade Strength		X		X		
Existing Conditions						
Standing/Seeping Water	X		X	X	X	X
Subgrade Support		X				
Pavement Thickness		X		X	X	
Slope Ratio	X					X
Pavement Distress		X	X	X	X	X

Exhibit 6.4-D ROADWAY SOILS ANALYSIS FACTORS

5. **Recommend**. Refer to Exhibit 6.4-E for a summary of applicable soil conditions for different foundation types. Select and recommend the foundation type that meets structure requirements and is best suited and most economical for site subsurface conditions.

6. **Perform Analysis**. Perform an analysis to provide the structural designer with at least the following information:

   - Recommended foundation type and bottom of footing or pile tip elevations.
   - Ultimate bearing capacity of foundation unit and recommended allowable or design value with appropriate factors of safety.
   - Limitations and/or potential problems with the recommended foundation type.
   - Suitable alternative foundation types.
   - Potential construction problems and recommended construction control measures.

Recommended minimum and typical ranges for factor of safety for the geotechnical soil substructure interaction are as follows:

Foundation Type	Use	Applicable Soil Conditions
Spread Footing	Individual columns, walls, bridge piers.	Any conditions where bearing capacity is adequate for applied load. May use on single stratum; firm layer over soft layer or soft layer over firm layer. Check immediate, differential and consolidation settlements.
Mat Foundation	Same as spread and wall footings. Very heavy column loads. Usually reduces differential settlements and total settlements.	Generally soil bearing value is less than for spread footings; over one-half area of building covered by individual footings. Check settlements.
Friction Piles	In groups to carry heavy column, wall loads. Requires pile cap.	Low strength surface and near surface soils. Soils of high bearing capacity 18 m to 45 m (60 ft to 150 ft) below ground surface, but by disturbing load along pile shaft solid strength is adequate. Corrosive soils may require use of timber or concrete pile material.
End Bearing Piles	In groups of at least 2 to carry heavy column, wall loads. Requires pile cap.	Low strength surface and near surface soils. End of pile located on soils 7.5 m to 30 m (25 ft to 100 ft) below ground surface.
Drilled Shafts (End bearing)	Larger column loads than for piles but eliminates pile cap by using caissons as column extension.	Low strength surface and near surface soils. End of shaft located on soils 7.5 m to 30 m (25 ft to 100 ft) below ground surface.
Sheetpile	Temporary retaining structures for excavations, alloy waterfront structures, cofferdams.	Any soil. Waterfront structures may require special or corrosion protection. Cofferdams require control of fill material.

Exhibit 6.4-E PRELIMINARY FOUNDATION TYPE SELECTION

1. **Shallow Foundations**. For shallow foundations, the factors of safety are:

Bearing Capacity	—	3.0
Sliding Along Base	—	1.5
Overturning (Rotational Failure)	—	2.0

2. **Deep Foundations**. For deep foundations, the factors of safety are:

Driven Piles (Static Method)	—	2.0 to 3.0
Drilled Shafts	—	2.0 to 2.5

Forms 6.4-I and 6.4-J illustrate samples of forms that are used to present allowable bearing capacities. In addition, settlement criteria should be established for specific subsurface conditions and structural requirements. The typical settlement criteria is a maximum 40 (1.5 in) to 50 mm (2 in) settlement that corresponds to 20 (0.75 in) to 25 mm (1 in) differential settlement between substructure units at allowable structural loadings.

The Geotechnical Unit is also responsible for ensuring that pile foundations can be installed to the design requirement without damage. In situations where concrete piles, high lands or difficult installation is anticipated, dynamic pile analysis is often performed. The wave equation computer program is often used to establish installation equipment requirements and pile stress during construction. As an alternative and/or supplement to the wave equation, dynamic pile monitoring during actual installation may be used. Detailed information on these procedures, along with other detailed structural foundation analysis techniques and design procedures, are provided in the FHWA *Soils and Foundation Workshop Manual* and the *Manual on Design and Construction of Driven Pile Foundations*.

Structure foundation investigations are usually confined to the area of the substructure units. Open communication and a close working relationship with the structural design engineer is required to provide an efficient, cost-effective analysis of foundations. The following provides the basic procedural steps for a typical structural geotechnical investigation:

1. **Initiate Project**. The following applies:

   - Identify available preliminary information (see Form 6.3-A).

   - Obtain or review other preliminary pertinent project development information from the Programming and Coordination Unit or the Project Development Unit, as applicable.

2. **Review Available Geotechnical Data**. The following applies:

   - Review as-constructed plans for any existing structure at or near the proposed project site.

   - Review any geotechnical reports and subsurface information for structures in the vicinity of proposed site.

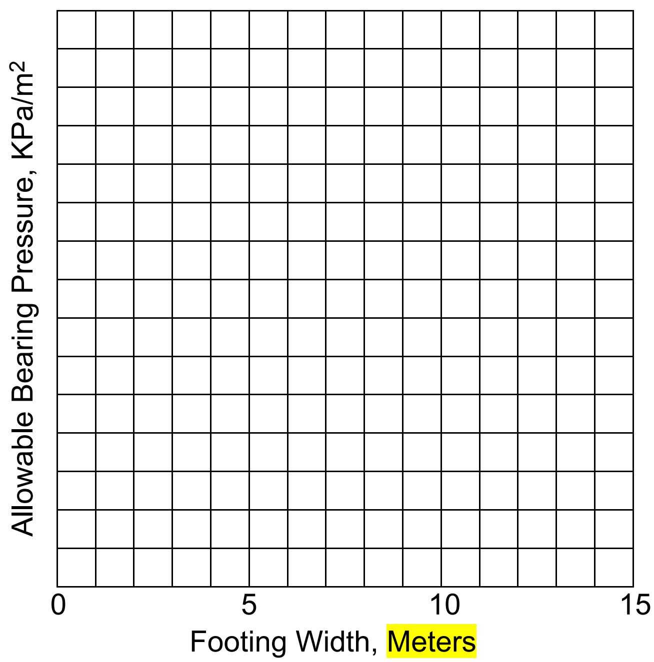
   - Review published information (see Exhibit 6.3-B). Place emphasis on localized geological and USDA soil survey information.

Allowable Bearing Pressure for Spread Footings

Project:____

Footing Location:_______________________________________

Designer:______________________________ Date: ____________



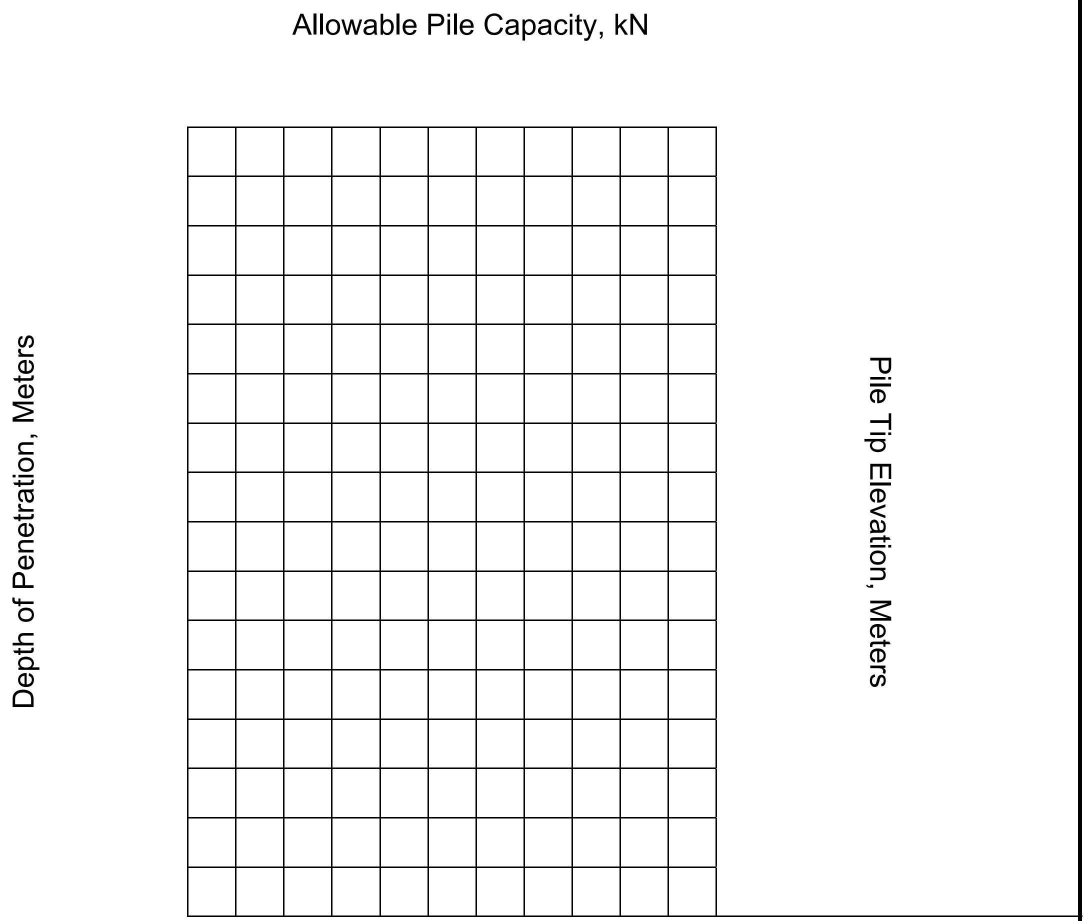
Design Criteria:

1. Soil Type: ______________________
2. Factor of Safety: __________________
3. Minimum Soil Above Footing Elevation: ____
4. Minimum Depth to Water Table: _________
5. Settlement at Bearing Pressure: _________
6. Maximum Total Settlement: _________

Form 6.4-I ALLOWABLE BEARING PRESSURE FOR SPREAD FOOTINGS (Metric)

To Be Provided

Form 6.4-I ALLOWABLE BEARING PRESSURE FOR SPREAD FOOTINGS (US Customary)



Project: ______________________________

Location:______________________________

Substructure Unit: Factor of Safety: ____________________

Form 6.4-J ALLOWABLE PILE CAPACITY CURVE
(Metric)

To Be Provided

Form 6.4-J ALLOWABLE PILE CAPACITY CURVE
(US Customary)

- Obtain a bridge layout sheet from the Bridge Unit.

3. **Plan Field Investigation**. The following applies:

- Determine drilling requirements (see Exhibit 6.3-E).
- Review the checklist for site investigation (Form 6.4-H) to identify the needed information to be collected.
- Discuss structure type and foundation requirements with the bridge engineer.
- Determine preliminary equipment requirements (see Exhibits 6.3-B, 6.3-D, 6.3-F and 6.3-K).
- Determine site restrictions. A site visit may be required.
- Develop a preliminary boring and testing plan (see Form 6.3-B).

4. **Plan Sampling and Testing**. The following applies:

- Determine sampling and testing requirements (see Exhibits 6.3-B, 6.3-E, 6.3-G and 6.3-U).
- Make preliminary selection of applicable foundation types (see Exhibit 6.4-E).
- Record field information (see Forms 6.3-C, 6.4-D, 6.4-H and 6.4-K through 6.4-R, as applicable).

5. **Summarize Field Data**. The following applies:

- Review Exhibit 6.3-Q and Form 6.4-A.
- Summarize soil profile information (see Form 6.4-G and Exhibit 6.4-B).

6. **Perform Analysis and Write Report**. The following applies:

- Review checklist items for spread footings (Form 6.4-K), piles (Form 6.4-L) and drilled shafts (Form 6.4-M), as applicable.
- Provide allowable bearing pressure (Exhibit 6.4-I) and pile capacity (Form 6.4-J), as applicable.
- Refer to the General Report Checklist (Form 6.4-G) and the Site Investigation Checklist (Form 6.4-A) to ensure appropriate report content.
- Finalize the report.

Spread Footings Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box: Yes	No	Not Applicable
1. Are spread footings recommended for foundation support or provided as an alternative to deep foundations?			
2. Are recommended bottom of footing elevations and reasons for recommendations (e.g., based on frost depth, estimated scour depth or depth to competent bearing material) given?			
3. Are the recommended allowable soil or rock bearing pressures given?			
4. Are estimated footing settlements given?			
5. Where spread footings are recommended to support abutments placed in the bridge end fills, are gradation and compaction requirements provided for select end fill and backwall drainage material?			
6. Have the following important construction considerations been adequately addressed?			
a. Materials on which the footing is to be placed — method by which project inspector can verify that material is as expected?			
b. Excavation requirements — safe slopes for open excavations, need for sheeting or shoring?			
c. Fluctuation of groundwater table?			
7. Are necessary contract special provisions provided?			

Comments ______________________________

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Form 6.4-K SAMPLE OF SPREAD FOOTING CHECKLIST

Piles Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box		
	Yes	**No**	**Not Applicable**
1. Are most suitable pile types (displacement, nondisplacement, pipe pile, concrete pile, H-pile, etc.) analyzed?			
2. Are reasons given for choice and/or exclusion of certain pile types?			
3. Are estimated pile lengths and estimated tip elevations given?			
4. Are recommended allowable pile design loads given?			
5. Has pile group settlement been estimated? (only of practical significance for friction pile groups in cohesive soils or large heavy structures on friction pile groups in sand)			
6. If a specified or minimum pile tip elevation is recommended, is the reason given for the required tip elevation? (e.g., under-lying soft layers, scour, downdrag, piles uneconomically long, etc.)			
7. Has design analysis verified that the recommend pile type can be driven tot he estimated or specified tip elevation without damage? (especially applicable where dense gravel-cobble-boulder layers or other obstructions have to be penetrated)			
8. Where the bridge abutment is to be supported on end-bearing piles and significant long-term settlement of the subsoil will occur (e.g., for embankments built over clays or soils with high organic content):			
a. Has abutment downdrag load been estimated and considered in design?			
b. Has bridge approach slab been considered to moderate differential settlement between bridge ends and fill?			
9. If the majority of subsoil settlement will not be removed prior to abutment construction, has estimate been made of the amount of abutment rotation that can occur due to lateral squeeze of soft subsoil?			

Form 6.4-L SAMPLE OF PILES CHECKLIST

Piles Checklist

Project: ____________________

Location: ____________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
10. Has horizontal abutment movement been considered?			
11. Has pile load test program or dynamic testing been considered?			
12. For a structure in high seismic risk area, has assessment been made of liquefaction potential of foundation soil during design earthquake? (Note only loose saturated sands and silts are “susceptible” to liquefaction)			
13. Construction considerations - have the following important construction considerations been adequately addressed?			
a. Pile driving details and what may be encountered during driving such as boulders or other obstructions (any need for pre-augering, jetting, spudding, pile tip reinforcement, driving shoes, etc.?)			
b. Excavation and the need for sheeting or shoring? (Safe slopes for open excavating)			
c. Fluctuations in groundwater table?			
d. Have effects of pile driving operation on adjacent structures been evaluated (e.g., protection against damage caused by footing excavations or pile driving vibrations)?			
e. Should preconstruction condition survey be made on adjacent structures (to document for possible construction damage claims)?			

Comments

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Form 6.4-L PILES CHECKLIST
(Continued)

Drilled Shaft Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ______________________ **Date:** ______________________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Recommended shaft diameter(s) and length?			
2. Allowable design load given for various diameter shafts recommended?			
3. Allowable end bearing value given?			
4. Allowable side friction value given?			
5. Settlement estimated for recommended design load?			
6. Where lateral load capacity of shaft is an important design consideration, are P-Y (load versus deflection) curves or soils data provided in geotechnical report which will allow structural engineer to evaluate lateral load capacity of shaft?			
7. Is static load test (to plunging failure) recommended?			
8. Construction considerations?			
a. Have construction methods been evaluated? (i.e., can dry method or slurry method be used or will casing be required)			
b. If casing will be required, can casing be pulled as shaft is concreted? (this can result in significant cost savings on very large diameter shafts)			
c. If artesian water may be encountered in the shaft excavation, have provisions been included? (such as by requiring casing and tremie seal)			
9. Are boulders likely to be encountered? (Note - if boulders are likely to be encountered, then the use of shafts should be questioned due to serious construction installation difficulties and possible higher costs.)			
10. Are recommended contract special provisions provided?			

Comments

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Form 6.4-M SAMPLE OF DRILLED SHAFT CHECKLIST